Effect of Naturally Occurring Hematite on Mechanical and Electrical Properties on Natural Rubber Composites

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ABSTRACT: The effect of naturally occurring hematite (α-Fe_2O_3) particles on composites based on natural rubber (NR) was investigated. The matrix was composed of 100g of NR, whereas α-Fe_2O_3 particles obtained from Kastina State in Nigeria were loaded in varying amounts of 3g, 5g and 7g. The compounding of the constituent materials was achieved with the aid of a two-roll mill in line with ASTM D15-627. The compounded mixtures were processed into their final shapes using compression molding machines. Tensile properties and flexural properties of the resultant composite samples were studied based on ASTM D638 and ASTM D7264/ASTM D7264M-07, respectively. On the other hand, the electrical conductivity of the samples was investigated in line with ASTM D257-07. The mineralogical composition of the filler sample was studied through the use of X-ray Fluorescence (XRF). XRF results showed that the filler was predominantly composed of α-Fe_2O_3. Tensile properties and flexural properties increased due to an increase in filler content. Additionally, the electrical conductivity of the composites increased with an increase in filler loading. Scanning electron microscope (SEM) images revealed filler-matrix adhesion in the composite samples. From the foregoing, α-Fe_2O_3 can serve as an alternative reinforcement for NR-based composites.

KEYWORDS: Natural rubber, hematite, tensile properties, flexural properties, electrical conductivity

https://doi.org/10.29294/IJASE.10.1.2023.3178-3185 **©2023 Mahendrapublications.com, All rights reserved**

1. INTRODUCTION

Natural rubber (NR) is a naturally occurring polymer composed primarily of poly (cis-1,4-isoprene). It is an essential elastomer with outstanding mechanical properties (such as improved flexibility, resilience, abrasion resistance elasticity, etc.) and extensively employed in various areas of engineering and industrial applications [1]. For instance, it has useful applications in the manufacture of products which are utilized in personal protection, road construction and medical related fields [2, 3, 4]. However, raw dry natural rubber is not often used in its original state for any engineering and domestic applications due to challenges associated with the material in its raw state. Accordingly, processing of rubber entails incorporating secondary materials referred to as additives. The incorporated additives ensure that the rubber compounds are well processed and vulcanized so as to enhance the end use properties of the final rubber articles. Additives often utilized in processing rubber articles are accelerators, fillers, vulcanizing agents, retarders, activators, etc. [*5*]. The final properties of NR composites do not solely depend on NR polymer. They are also dependent on filler particles infused into NR polymer. Fillers are among the most essential additives integrated into rubber matrices. The principal aim why fillers are incorporated is to boost some properties of the end product. Hence, utilization and proper dispersion of filler within rubber compounds enhances markedly, the overall properties of end rubber products, while reducing their cost [6-9]. The dispersion of filler inside rubber matrix is achieved by the rubber composition, filler structure, and compounding conditions and arrangement [1]. There are two types of fillers namely: reinforcing fillers and non-reinforcing fillers. Reinforcing fillers serves to boost the mechanical properties. In addition, they bring about enhanced properties that meet targeted end uses. On the other hand, non-reinforcing

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Received: 11.06.2023 **Accepted:** 17.07.2023 **Published on**: 25.08.2023

fillers are used mostly as extenders with the purpose of bringing down the cost of the end rubber articles. Typical examples of non-reinforcing fillers include: carbonates, silicates and different clays (kaolin) [1]. The most commonly employed reinforcing filler employed in rubber related industrial applications is carbon black (CB). On the other hand, CB possesses certain drawbacks such as its non-renewable nature or origin, pollution, toxicity and black colored nature which often leads to contamination. Therefore, there is ongoing research aimed at partial or full substitution of CB with viable choices [1, 10, 11].

Moreover, infusion of fillers into elastomeric matrices permits the adjustment of the mechanical and structural properties of resultant composites, as well as their electrical properties [11]. Addition of metal oxides like aluminum oxide (Al_2O_3), titanium dioxide (TiO_2) and silicon oxide (SiO_2) as fillers in polymeric matrices can yield simultaneous boost in mechanical and electrical properties among other desired properties [3,12,8]. Recently, iron oxides such as α-Fe_2O_3 and magnetite (Fe_3O_4) have attracted lots of attention in coming up with novel materials. This is due to their interesting electrical and magnetic characteristics, among other characteristics [13, 24]. Of all iron oxides, α-Fe_2O_3 also called ferric oxide (FO) is the most stable. It possesses interesting properties like electrical semi-conductivity (10^{-6} S/cm), ferrimagnetic properties, high corrosion resistance and low cost. Owing to the afore mentioned properties, it has found applications in producing catalysts, gas sensors, pigments, anti-corrosive agents, magnetic recording media, and lithium ion batteries with great scientific and technical importance [15,16,17].

The objective of this study is to study some mechanical and electrical properties of NR composites loaded with naturally occurring α-Fe_2O_3 filler particles. This is aimed at coming up with alternative NR-based articles for outdoor, electrical and other industrial usage.

2.0 MATERIAL AND METHODS

2.1 Materials

NR latex was obtained from Rubber Research Institute of Nigeria (RRIN), Benin City, Edo State. Zinc oxide (ZnO), stearic acid, sulphur, mecarptobenzothiazole (MBT) and 1,2-dihydro-2,2,4-trimethylquinoline (TMQ), were purchased from Stevemoore Chemical Co. Zaria, Kaduna State, Nigeria. Hematite (α-Fe_2O_3) was obtained from natural deposits domiciled in Katsina State, Nigeria and crushed to particle size of 10 µm. The constituents were compounded and subsequently processed into final composite shapes at Polymer Recycling Workshop, Nigerian Institute of Leather and Science Technology, Zaria.

Table 1: Material Composition

Materials	Weight (g)
NR/α-Fe_2O_3	100/3, 100/5, 100/7
Zinc Oxide (ZnO)	5.0
Sulphur	2.0
Stearic Acid	2.0
MBT	1.5
TMQ	1.0

2.2 Preparation of NR/α-Fe_2O_3 Composites

The composites were compounded using two roll mill in accordance with ASTM D15-627 standard. The method was as follows. NR was introduced into the two roll mill and allowed to melt 2 minutes. After that, the additives were added and allowed to blend for 3 minutes. Later on, α-Fe_2O_3 particles were infused and allowed to mix for 3 minutes. Finally, sulphur was introduced and the resultant mixture was allowed to mix for 3 minutes. The resultant mixture was transferred into a mould of 3mm thickness and subsequently compressed into its final shape by the aid of a compression moulding machine at a 140°C temperature and 4MPa pressure, for about 7 minutes.

2.3 Mechanical Properties Test

Tensile and flexural properties of the composite were determined using Instron Universal Testing Machine (System ID No. 3369K1781) having a capacity of 50kN. Evaluation of the tensile properties was done in line with ASTM D638. On the other hand, the samples' flexural properties were investigated in accordance with ASTM D7264/ASTM D7264M-07.

2.4 Electrical Conductivity Test

Electrical conductivity of the produced composite samples was measured by the use of two-point technique and in line with ASTM D257-07. A DC voltage source applied a voltage of about of 24V across each sample under measurement, causing a current (I) to flow through each sample. The resistance (R) was determined by a multi metre capable of measuring high resistances. The volume resistivity (ρ) of the each composite sample expressed in Ωcm, was achieved by measuring the resistance and dimensions of the sample of length (l), height (h), and width (w) using the equation (*Heaney, 2004*):

$$\rho = \frac{\mathrm{Rw\,h}}{\mathrm{l}} \qquad (1)$$

The electrical conductivity (σ) of the samples expressed in S/cm was achieved by the equation (*Heaney, 2004*):

$$\sigma = \frac{1}{\rho} \qquad (2)$$

2.5 Mineralogical Analysis of α-Fe₂O₃ Particles

The mineralogical analysis of the filler particles was done with EDX-720 X-ray Fluorescence (XRF) spectrometer.

2.6 Morphological Analysis of NR/α-Fe₂O₃ Composites

Characterization of NR/α-Fe_2O_3 composite samples was carried out using Fourier Transform Infrared (FTIR) Spectroscopy using Shimadzu FTIR-8400S machine. The dispersion of the filler particles within the NR matrix was studied using Carl Zeiss Scanning Electron Microscopy (SEM), Model EVO LS10.

3.0 RESULTS AND DISCUSSION

3.1 Mechanical Property Result

(i) Tensile strength

As revealed by Figure 1, unfilled NR displayed the least tensile strength. This was occasioned by the absence of any kind of reinforcement in the matrix [18]. In addition, the aforementioned figure shows that increase in filler composition contributed to increase in tensile strength of the composites. This is because α-Fe_2O_3 filler particles added into the matrix system performed the role of stress concentrators or reinforcements. Consequently, this led to efficient transfer of stress from NR matrix to the filler particles [19]. In addition, α-Fe_2O_3 just like every other ferrite confers considerable level of reinforcement to resultant composites [20, 9].

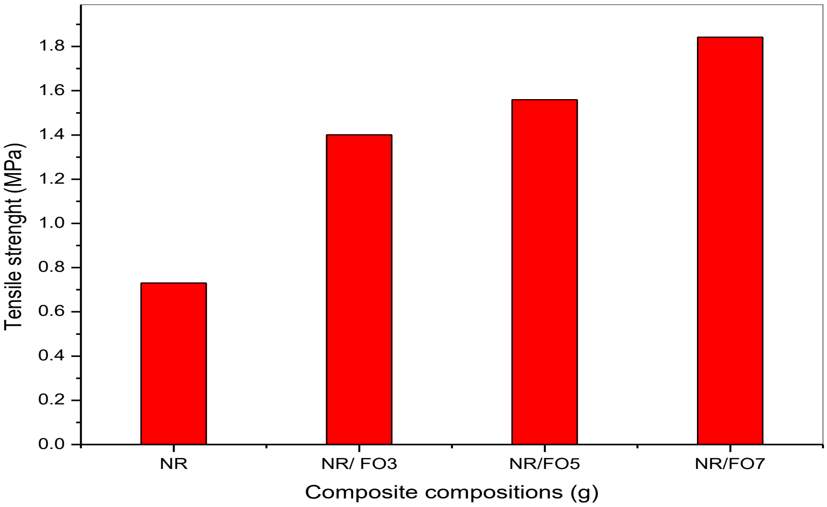

Fig. 1 Graph of tensile strength of NR/α-Fe₂O₃ composites

(ii) Tensile Modulus

Tensile modulus of each sample is illustrated by Figure 2. It can be observed that when compared with tensile modulus of NR sample (control), appreciation in filler particle content led to improvement in tensile modulus of the composites. This is because integration of filler particles into rubber matrices brought about enhancement in stiffness of resultant composites upon the application of a load [6, 11]. Also, α-Fe_2O_3 particles present in the matrix confers improved resistance to penetration therefore greater stiffness was achieved [21]

(iii) Elongation at break

Elongation at break of the samples is described by Figure 3. It can be noted that infusion of increasing amounts of filler particles made for depreciation of elongation at break of the samples. This was brought about by availability of the filler particles within the elastomer. As a result, there occurred a limitation of the elastomer's chain movement which lowers the elasticity [10,9].

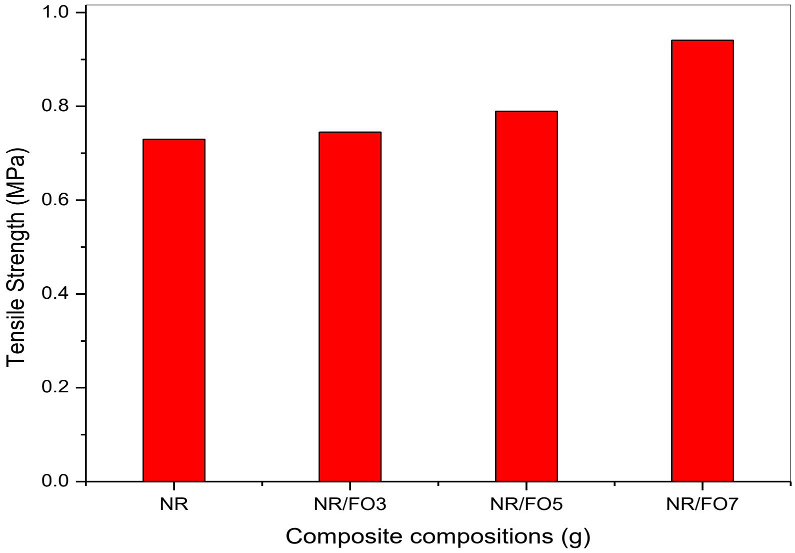

Fig. 2: Graph of tensile modulus of NR/α-Fe_2O_3 composites

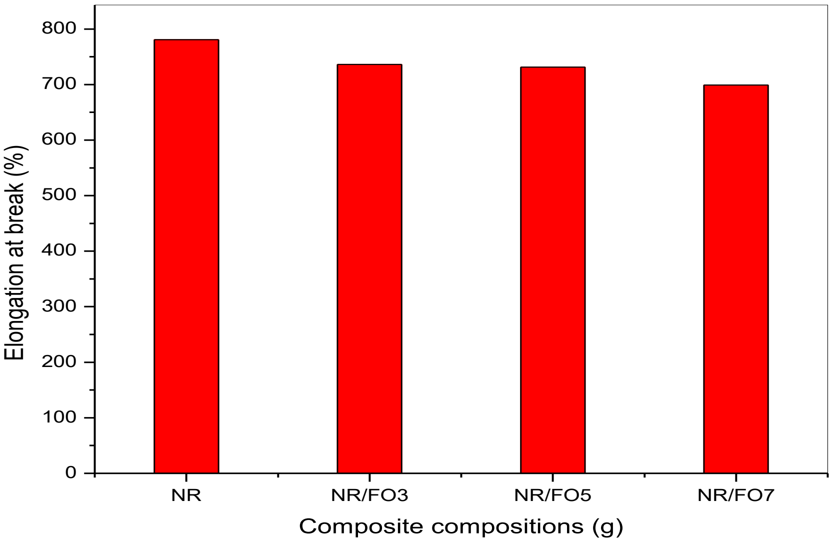

Fig. 3 Graph of elongation at break of NR/α-Fe_2O_3 composites

(iv) Flexural Strength

Flexural strength of each composite is displayed by Figure 4. When compared with the flexural strength of the control sample (NR), the flexural strength of the composites increased with increase in filler content. This is attributed to the increasing bonding of the filler particles to the NR matrix, as the amount of filler increased [18, 19].

(v) Flexural Modulus

The flexural modulus of the composites is illustrated by Figure 5. It can be observed that in a like manner to flexural strength of the samples. In comparison with unfilled NR (control), improvement in flexural modulus of the composite samples was occasioned by rise in filler loading. As earlier stated, this situation is ascribed to the expanding matrix-filler cohesion as the amount of filler increased [22, 7].

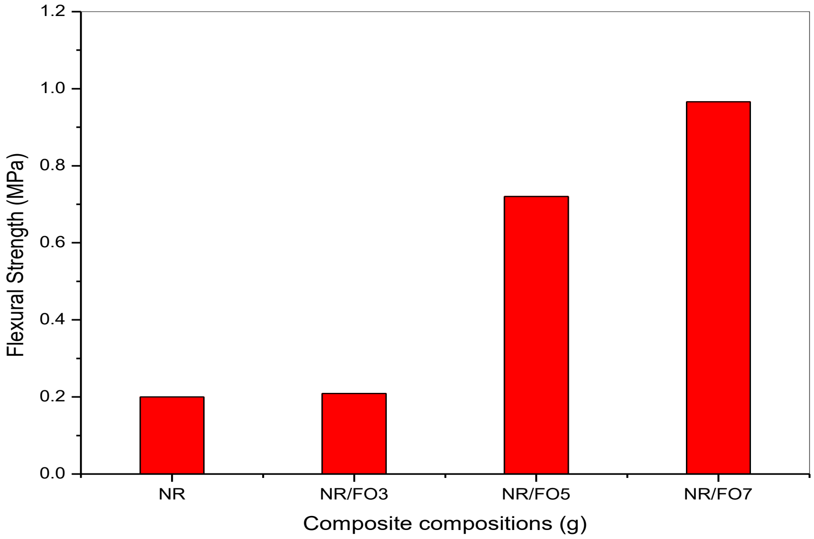

Fig. 4 Graph of flexural strength of NR/α-Fe_2O_3 composites

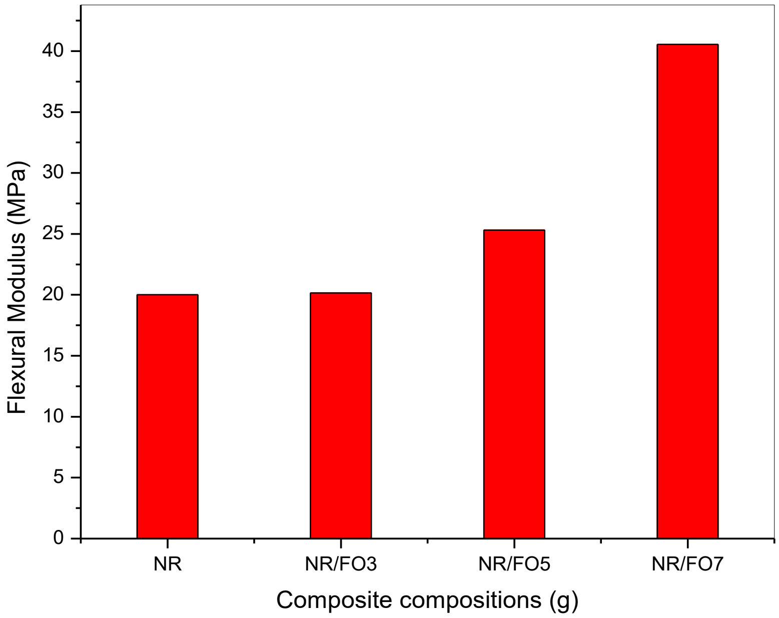

Fig. 5 Graph of flexural modulus of NR/α-Fe_2O_3 composites

3.2 ELECTRICAL PROPERTY RESULTS

(i) Electrical Conductivity

Fig. 3.6 displays the results obtained from measurement of electrical conductivity of the composites. It is shown that increase in α-Fe_2O_3 filler content caused an increase in the electrical conductivity of the composites. This was occasioned by decrease between the filler particles inside the NR matrix, upon addition of increasing filler amount. Consequently, this brought about formation of conductive pathways for the charge carriers in the filler particles [14]. On the other hand, infusion of α-Fe_2O_3 only brought about marginal increase in the insulation properties, hence, the composites displayed conductivities typical of electrical insulators (between $10^{-10}$and 10^{-20}S/cm) [23,4]. This occurrence was due attributed to the varying amounts of filler particles incorporated were not up to the amount required to bring about the formation of a continuous and conductive filler network within the NR matrix [10, 11]. Consequently, any sort of contribution to electrical conductivity was due to hopping of charge carriers between conductive sites [1].

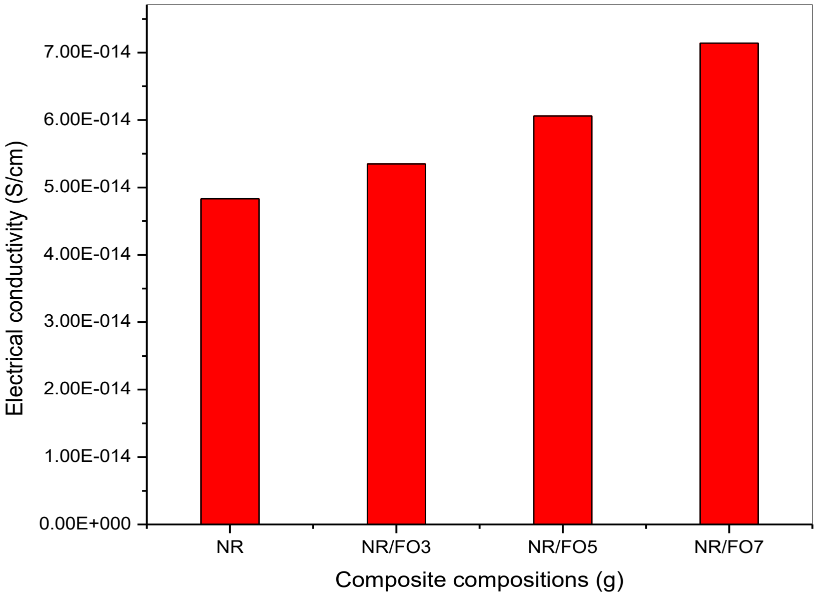

Fig. 6: Graph of electrical conductivity of NR/α-Fe_2O_3 composites

3.3 X-ray Fluorescence (XRF) Result

XRF analysis result of the mineralogical composition of filler samples is presented in Table 2 The result show that α-Fe_2O_3 is the dominant oxide present in the filler sample. As further depicted by Table 2, other oxides are contained in the filler particles. This is because just like all other mineral which occurs naturally, α-Fe_2O_3 does not occur in isolation. It possesses impurities which are oxides of other metals [5, 1]. Finally, it can be noted from the aforementioned table that the other oxides present were of insignificant amounts when compared to the amount of α-Fe_2O_3 present in the filler sample. Hence this filler sample is a high grade α-Fe_2O_3 [14].

Table 2: Mineralogical composition of filler sample

Analysis	Content (%)
Haematite (Fe_2O_3)	54.118
Copper (II) oxide (CuO)	1.768
Titanium dioxide (TiO_2)	7.027
Nickel dioxide (NiO)	0.147
Vanadium pentoxide (V_2O_5)	0.331
Potassium oxide (K_2O)	0.082
Silicon oxide (SiO_2)	34.289
Manganese (II) oxide (MnO)	0.382
Niobium monoxide (NbO)	0.074
Lead monoxide (PbO)	0.053

3.4 SEM Morphological Analysis of Composites

Figure 7(a) displays the SEM image of unfilled NR (control). In addition Figure 7(b) reveals the SEM image of sample NR/FO7. Here, α-Fe_2O_3 filler particles acting as reinforcement appear as white spots inside the NR matrix [12]. This improved the investigated mechanical properties of the produced composites. Furthermore as depicted by Fig. 7(b), some filler particles were close to each other. This created some measure of conduction pathway for the charge carriers to flow. Hence this resulted in improvement in electrical conductivity of the samples [7,24].

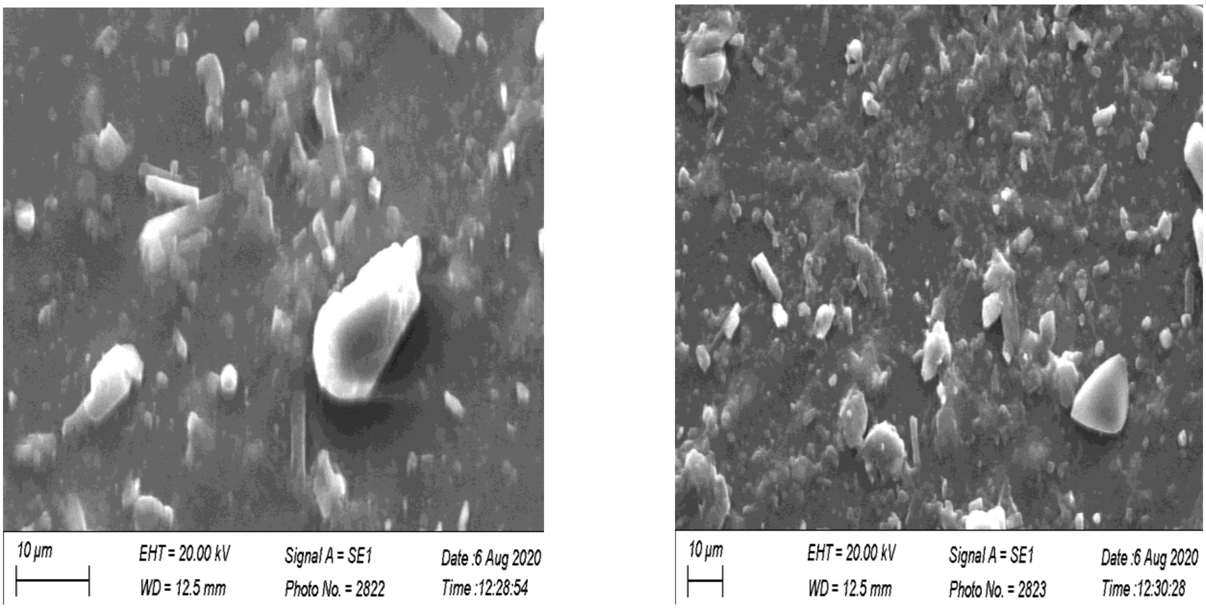

Fig.7 SEM image of (a) NR **(b) NR filled with 7g of α-Fe_2O_3**

CONCLUSION

Composites containing 7g of α-Fe_2O_3 showed the best tensile, flexural and electrical properties. Hence, from the foregoing, it is observed that naturally occurring α-Fe_2O_3 obtained in Nigeria can find application as alternative filler material in NR-based composites. In addition, owing to the semiconducting property of α-Fe_2O_3, its presence brought about a marginal step up in the electrical conductivity of the composites. However, due to the amount of filler added, the composites are within the range of insulators.

ACKNOWLEDGMENT

The contributions of Department of Polymer and Textile Engineering, Federal University of Technology Owerri Imo State and Polymer Recycling Workshop, Nigerian Institute of Leather and Science Technology, Zaria towards completion of this work are highly acknowledged.

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